

# Biomass Burning and Aerosol Characteristics in India

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# Introduction

AIR POLLUTION IN NUMBERS

## AIR POLLUTION AFFECTS NEARLY ALL OF US

An estimated **6.5 million** deaths were associated with air pollution in 2012. This is **11.6% of all global deaths.**

WHO Report

## Fourteen out of the world's most-polluted 20 cities are in India

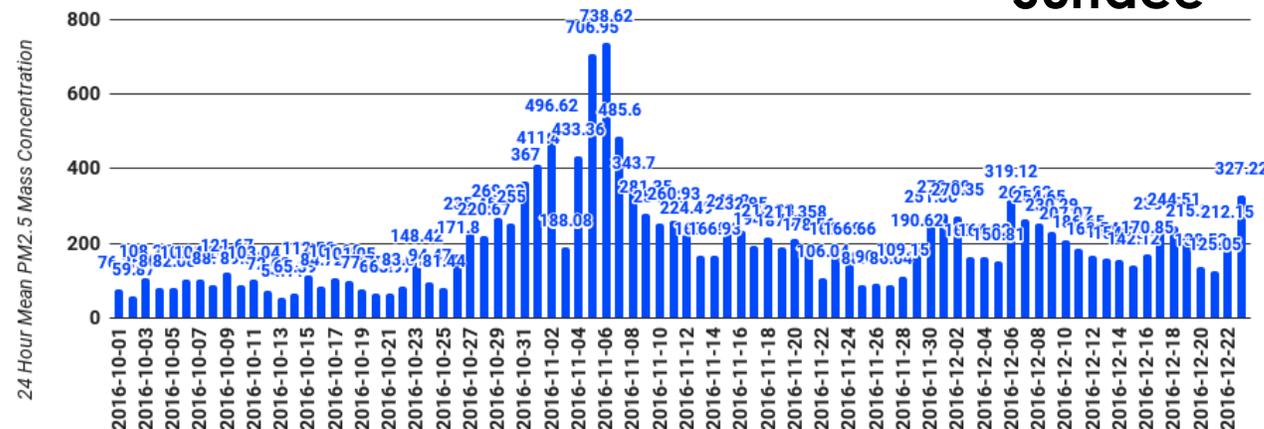
City	*PM2.5	City	*PM2.5
Kanpur	173	Gurgaon	113
Faridabad	172	Jaipur	105
Varanasi	151	Patiala	101
Gaya	149	Jodhpur	98
Patna	144	Baoding	93
Delhi	143	Ulaanbaatar	92
Lucknow	138	Hengshui	87
Agra	131	Xingtai	87
Muzaffarpur	120	Anyang	86
Srinagar	113	Liaocheng	86

\*(Annual mean, ug/m3)

Source: World Health Organization



US Embassy AQ Station, Delhi



## Can be seen from a million miles away



# Four plus decades of research over India

## Aerosol Properties

- Photometry aboard rocket
- INDOEX field campaign
- Regional field campaign
- Decadal change in aerosols from satellite



GEOPHYSICAL RESEARCH LETTERS, VOL. 38, L14811, doi:10.1029/2011GL048153, 2011

### A decade of change in aerosol properties over the Indian subcontinent

Sagnik Dey<sup>1</sup> and Larry Di Girolamo<sup>2</sup>

Received 16 May 2011; revised 9 June 2011; accepted 1 June 2011; published 29 July 2011.

[1] Changing atmospheric aerosol properties caused by anthropogenic activities carries serious implications for climate change and human health. The launch of the Multi-angle Imaging SpectroRadiometer (MISR) onboard *Terra* spacecraft more than a decade ago provides the first capability to monitor several physical properties of aerosols over land from space. We use ten years (Mar 2000–Feb 2010) of observations from MISR to quantify seasonal linear trends of aerosol optical depth ( $\tau$ ) segregated by particle size and shape over the Indian subcontinent. Here we show that many regions (referred to here as hotspots) have statistically significant (i.e.,  $p < 0.05$ ) seasonal linear trends in  $\tau$ , with seasonal  $\tau$  increasing in the range 0.1–0.4 in the last decade. These hotspots are associated with urban centers and

region (e.g., *Zhang and Reid* [2010] focused on the oceanic region), or an average over the entire area of the Indian subcontinent [e.g., *Streets et al.*, 2009]. A comprehensive analysis of temporal changes in aerosol characteristics and their attributions are still lacking in the subcontinent, particularly where space-time coverage of long-term in-situ observations are not adequate to understand the potential impacts of aerosols on regional climate, monsoon circulation and human health.

[3] We recently reported on the first satellite-based climatology of aerosol optical and microphysical properties over the Indian subcontinent retrieved by the Multiangle Imaging SpectroRadiometer (MISR) [*Dey and Di Girolamo*, 2010], where the relative contribution of anthropogenic and

2011

Atmospheric Environment  
journal homepage: v

ELSEVIER

### Investigations of aerosol black carbon over the Indo-Gangetic Plain region

Hema Joshi<sup>a,b</sup>, Manish Naja<sup>a,c</sup>, K.P. Singh<sup>c</sup>, R. S.K. Satheesh<sup>f</sup>, K. Krishna Moorthy<sup>g</sup>, H.C. Chakrabarty<sup>h</sup>

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<sup>c</sup>G. B. Pant University of Agriculture and Technology, Pantnagar, India  
<sup>d</sup>Advanced Study Program, National Center for Atmospheric Research, Thiruvananthapuram  
<sup>e</sup>Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram  
<sup>f</sup>Centre for Atmospheric and Oceanic Sciences, Indian Institute of Space Science and Technology, Thiruvananthapuram  
<sup>g</sup>Indian Space Research Organization Head Quarters, Bangalore, India  
<sup>h</sup>Indian Institute of Space Science and Technology, Thiruvananthapuram

#### HIGHLIGHTS

- A complete seasonal variation of BC from a semi-urban to rural
- Large diurnal and seasonal variation with maximum in winter
- Surface BC is maximum in winter, unlike emission
- Unlike BC, CALIPSO extinctions at higher height and
- WRF-Chem simulated BC shows important features but underestimated

ARTICLE INFO

# Four plus decades of research over India

## Aerosol Properties Aerosol Sources

Several studies have been published that identify dust, biomass burning, biofuels, vehicular and industrial pollution as dominant sources of aerosols in the region but their relative contribution remain unknown

Journal of Atmospheric Environment (1967)  
1967, Pages 1259-1266

Areas in India

### Anthropogenic fine aerosols dominate the wintertime regime over the northern Indian Ocean

By KRISHNAKANT BUDHAVANT<sup>1,2,3</sup>, SRINIVAS BIKKINA<sup>1</sup>, AUGUST ANDERSSON<sup>1</sup>, EIJA ASMI<sup>4</sup>, JOHN BACKMAN<sup>4</sup>, JUTTA KESTI<sup>4</sup>, H. ZAHID<sup>3</sup>, S. K. SATHEESH<sup>2</sup> and ÖRJAN GUSTAFSSON<sup>1\*</sup>, <sup>1</sup>Department of Environmental Science and Analytical Chemistry, The Bolin Centre for Climate Research, Stockholm University, Stockholm, Sweden; <sup>2</sup>Centre for Atmospheric and Oceanic Sciences (CAOS), The Divecha Centre for Climate Change (DCCC), Indian Institute of Science, Bangalore, India; <sup>3</sup>Maldives Climate Observatory-Hanimaadhoo, Maldives Meteorological Services, Maldives; <sup>4</sup>Finnish Meteorological Institute, Helsinki, Finland

(Manuscript received 20 November 2017; in final form 5 April 2018)

**ABSTRACT**  
This study presents and evaluates the comprehensive set to date of chemical, physical and optical properties of aerosols in the outflow from South Asia during a full winter (Nov. 2014 – March 2015), here intercepted at the Indian Ocean receptor site of the Maldives Climate Observatory in Hanimaadhoo (MCOH). Cluster analysis of air-mass back trajectories for MCOH, combined with MODIS and meteorological data, demonstrate that the wintertime northern Indian Ocean is strongly influenced by aerosols transported from source regions with three major wind regimes, originating from the Indo-Gangetic Plain (IGP), the Bay of Bengal (BoB) and the Arabian Sea (AS). As much as 97 ± 3% of elemental carbon (EC) in the PM<sub>10</sub> was also found in the fine mode (PM<sub>2.5</sub>). Other mainly anthropogenic constituents such as organic carbon (OC), non-sea-salt (nss)-sulfate (SO<sub>4</sub><sup>2-</sup>) and NH<sub>4</sub><sup>+</sup> were also predominantly in the fine mode (70–95%), particularly in the air masses from IGP. The combination at this large-footprint receptor observatory of consistently low OC/EC ratio (2.0 ± 0.5), strong linear relationships between EC and OC as well as between nss-K and both OC and EC, suggest a predominance of primary sources, with a large biomass burning contribution. The particle number-size distributions for the air masses from IGP and BoB exhibited clear bimodal shapes within the fine mode.

**Abstract**  
Asia is undergoing rapid urbanization and pollution in Asia is studied using a Lagrangian puff transport model. Asian megacities cover <2% of the Asian anthropogenic sulfur emissions of Asia. It is shown that urban sulfur emissions contribute over 50% of the total sulfur emissions in large parts of Asia. The average contribution of megacities over the western Pacific increased from <5% in 1975 to >10% in 2000. Two future emission scenarios are evaluated for 2020—“business as usual (BAU)” and “maximum feasible controls (MAXF)” to establish the range of reductions possible for these cities. The MAXF scenario would result in 2020 S-emissions that are ~80% lower than those in 2000, at an estimated control cost of US \$87 billion per year (1995 US\$) for all of Asia. An urban scale analysis of sulfur pollution for four megacities—Shanghai, and Chongqing in China; Seoul in South Korea; and Mumbai (formerly Bombay) in India is presented. If pollution levels were allowed to increase under BAU, over 30 million people in these cities alone would be exposed to levels in excess of the WHO guidelines.

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PAGES 333–340

power plants [Prasad et al., 2006, 2012]. The degree to which different pollutants are at play, however, needs further study.

**How Pollution Spreads**  
With the onset of the winter months, the decrease in temperature results in lower boundary layer height, favoring the accumulation of pollutants near Earth's surface. In combination with the high relative humidity and other meteorological parameters (e.g., calm winds typical of post-monsoon months), weather promotes the formation of smog [Gautam et al., 2007] (see also Figure 1b). Analysis of MODIS aerosol optical depth (AOD) and data from NASA's Atmospheric Infrared Sounding satellite have shown higher AODs and carbon monoxide volume mixing ratios over the western IGP, with significant gradients toward the east during the peak of the burning period. Nitrogen dioxide concentrations also spike during the fires. Carbon monoxide and nitrogen dioxide are among the main elements of smog. Both also work to seed smog with ground-level ozone, a potent greenhouse gas.

# Four plus decades of research over India

Results on aerosol measurements from balloons

August 1991 · Indian Jo

Jayaraman Achuth

Overview Co

**Aircraft measurements from a coastal location of peninsular India**

Seasonal variation of vertical distribution of aerosol single scattering albedo over Indian sub-continent: RAWEX aircraft observations

Meridional gradients in aerosol vertical distribution over Indian Mainland: Observations and model simulations

black carbon over the north-east part of India

S.S. Puri, M. Gogoi, K. Krishna Moorthy

S.S. Puri, S. Suresh Babu, N.B. Lakshmi, S.K. Satheesh, K. Krishna Moorthy

**HIGHLIGHTS**

- Altitude profiles of aerosols
- Enhancement in free troposphere
- Near-surface loading pattern
- Pre-monsoon aerosols

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Keywords:  
Aerosols  
Vertical distribution  
Boundary layer

**ABSTRACT**

Multi-year observations from the network of ground-based observatories (ARFINET), established under the project 'Aerosol Radiative Forcing over India' (ARFI) of Indian Space Research Organization and space-borne lidar 'Cloud Aerosol Lidar with Orthogonal Polarization' (CALIOP) along with simulations from the chemical transport model 'Goddard Chemistry Aerosol Radiation and Transport' (GOCART), are used to characterize the vertical distribution of atmospheric aerosols over the Indian landmass and its spatial structure. While the vertical distribution of aerosol extinction shows higher values close to the surface followed by a gradual decrease at increasing altitudes, a strong meridional increase is observed in the vertical spread of aerosols across the Indian region in all seasons. It emerges that the strong thermal convections cause deepening of the atmospheric boundary layer, which although reduces the aerosol concentration at lower altitudes, enhances the concentration at higher elevations by pumping up more aerosols from below and also helping the lofted particles to reach higher levels in the atmosphere. Aerosol depolarization ratios derived from CALIPSO as well as the GOCART simulations indicate the dominance of mineral dust aerosols during spring and summer and anthropogenic aerosols in winter.

Aerosol Properties  
Aerosol Sources  
Vertical Distribution

Over the year aircrafts have been used to measure vertical profiles of aerosols and its properties along with CALIPSO over last decade

# Four plus decades of research over India

Anthropogenic fine aerosols dominate the wintertime regime over the northern Indian

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 109, D20211, doi:10.1029/2004JD004924, 2004

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Annual variations of the altitude distribution of aerosols and effect of long-range transport over the southwest Indian Peninsula



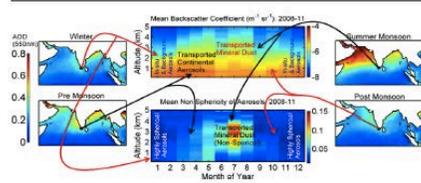
Manoj Kumar Mishra<sup>1</sup>, K. Rajeev, Bijoy V. Thampi<sup>1</sup>, Anish Kumar M. Nair

<sup>1</sup>Space Physics Laboratory, Vikram Sarabhai Space Centre, Thiruvananthapuram, India

## HIGHLIGHTS

- Long-term observations of aerosol altitude distribution in tropical Indian coast.
- Elevated layers of highly non-spherical aerosols in widespread aerosol plumes.
- Long-range transport enhances aerosol loading at 2–4 km altitude by 5–10 times.
- Highly systematic and prominent annual variation of aerosols at 2–4 km altitude.
- Variation of aerosol loading at <1 km altitude during different seasons are <20%.

## GRAPHICAL ABSTRACT



## ARTICLE INFO

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Aerosols

Keywords:  
Aerosols  
Angström exponent  
Single scattering albedo  
Biomass burning  
Radiative forcing  
Heating rate

## ABSTRACT

Annual variations of the altitude distribution of aerosols and the effect of long-range transport in modulating the aerosol loading over Thiruvananthapuram (8.5°N, 77°E), a relatively clean tropical station located in the southwest coast of Peninsular India, are investigated using dual polarization Micro Pulse Lidar observations carried out during March 2008–May 2011. Combined analysis of these lidar observations with the spatial distribution of aerosols derived from satellite data shows the occurrence of elevated layers of highly non-spherical aerosols in the 15–4 km altitude region, which are associated with the wide-spread aerosol plumes over the Arabian Sea during the pre-monsoon and summer-monsoon seasons. In contrast, ~90% of the column integrated aerosol backscatter coefficient ( $\beta_{\text{a}}$ ) is due to regional PM<sub>2.5</sub> during each post-monsoon season. We reproduce up to

Aerosol  
Properties  
Aerosol  
Sources  
Vertical  
Distribution  
Transport

Focused on spring-summer time dust and postmonsoon smoke transport

# Four plus decades of research over India

INTERNATIONAL JOURNAL OF CLIMATOLOGY  
Int. J. Climatol. 37 (Suppl. 1): 298–317 (2017)  
Published online 16 February 2017 in Wiley Online Library  
(wileyonlinelibrary.com) DOI: 10.1002/joc.5004

## Declining pre-monsoon dust loading over South Asia: Signature of a changing regional climate

Satyendra K. Pandey<sup>1</sup>, V. Vinoj<sup>1</sup>, K. Landu<sup>1</sup> & S. Suresh Babu<sup>2</sup>

Desert dust over the Indian region during pre-monsoon season is known to strengthen monsoon circulation, by modulating it in fall through the elevated heat pump (EHP) mechanism. In this context, an insight into long term trends of dust loading over this region is of significant importance in understanding monsoon variability. In this study, using long term (2000 to 2015) aerosol measurements from multiple satellites, ground stations and model based reanalysis, we show that dust loading in the atmosphere has decreased by 1.0 to 20% during the pre-monsoon season with respect to start of this century. Our analysis reveals that this decrease is a result of increasing pre-monsoon rainfall that in turn increases (decreases) wet scavenging (dust emissions) and slowing circulation pattern over the North western part of the sub-continent.

Mineral dust is among dominant natural aerosol species in the atmosphere, besides sea salt<sup>1</sup> and is generated due to wind erosion over arid and semiarid regions of the globe. It affects the Earth system through variety of processes. One such process is scattering and absorption of solar and terrestrial radiation, known as the direct radiative effect<sup>2–4</sup>. Another is by modulating cloud characteristics<sup>5–9</sup>, which alters radiative properties of cloud, known as the semi-direct and indirect radiative effects<sup>8,10</sup>. Besides important role in the atmospheric processes, deposition of dust due to long range transport on the glaciers are also found to have profound impact on the planetary albedo<sup>11,12</sup> and hence the radiation budget<sup>13</sup>. Dust also modulates atmospheric dynamics<sup>14–16</sup> through warming within the atmosphere thereby altering circulation patterns. Other than its effect on various components of the climate system<sup>17–20</sup>, mineral dust also has many other impacts, such as on marine productivity through nutrient deposition<sup>21</sup>, deterioration of air quality by contributing to particulate matter PM<sub>2.5</sub><sup>22</sup>, on human health by causing acute respiratory diseases<sup>23–25</sup>. The studies in the past have shown that the presence of large absorbing dust in the atmosphere can enhance the lower atmospheric warming<sup>27,28</sup>. For example, it has been shown that Indian summer monsoon rainfall is related to dust loading (both locally and remotely) at different time scales<sup>26,27,29–31</sup>. The elevated heat pump mechanism, which is a key feature of the monsoon dust from local sources combined with black carbon induced by anthropogenic aerosols. The Middle East dust by monsoon flow, which can transport more water vapor to southern region aerosols tend to enhance the southeasterly monsoon flow, all over northern India. Both dust and anthropogenic aerosol-induced rainfall responses can be attributed to their heating effect in the mid-to-upper troposphere, which enhances monsoon circulations. The heating effect of dust over the Iranian Plateau seems to play a bigger role than that over the Tibetan Plateau, while the heating of anthropogenic aerosols over the Tibetan Plateau is more important. Moreover, dust aerosols can decrease rainfall over the Arabian Sea through their indirect effect. This study addresses the relative roles of dust and anthropogenic aerosols in altering the ISM rainfall and provides insights into aerosol-ISM interactions.

Aerosol Properties

Aerosol Sources

Vertical Distribution

Transport

Impacts

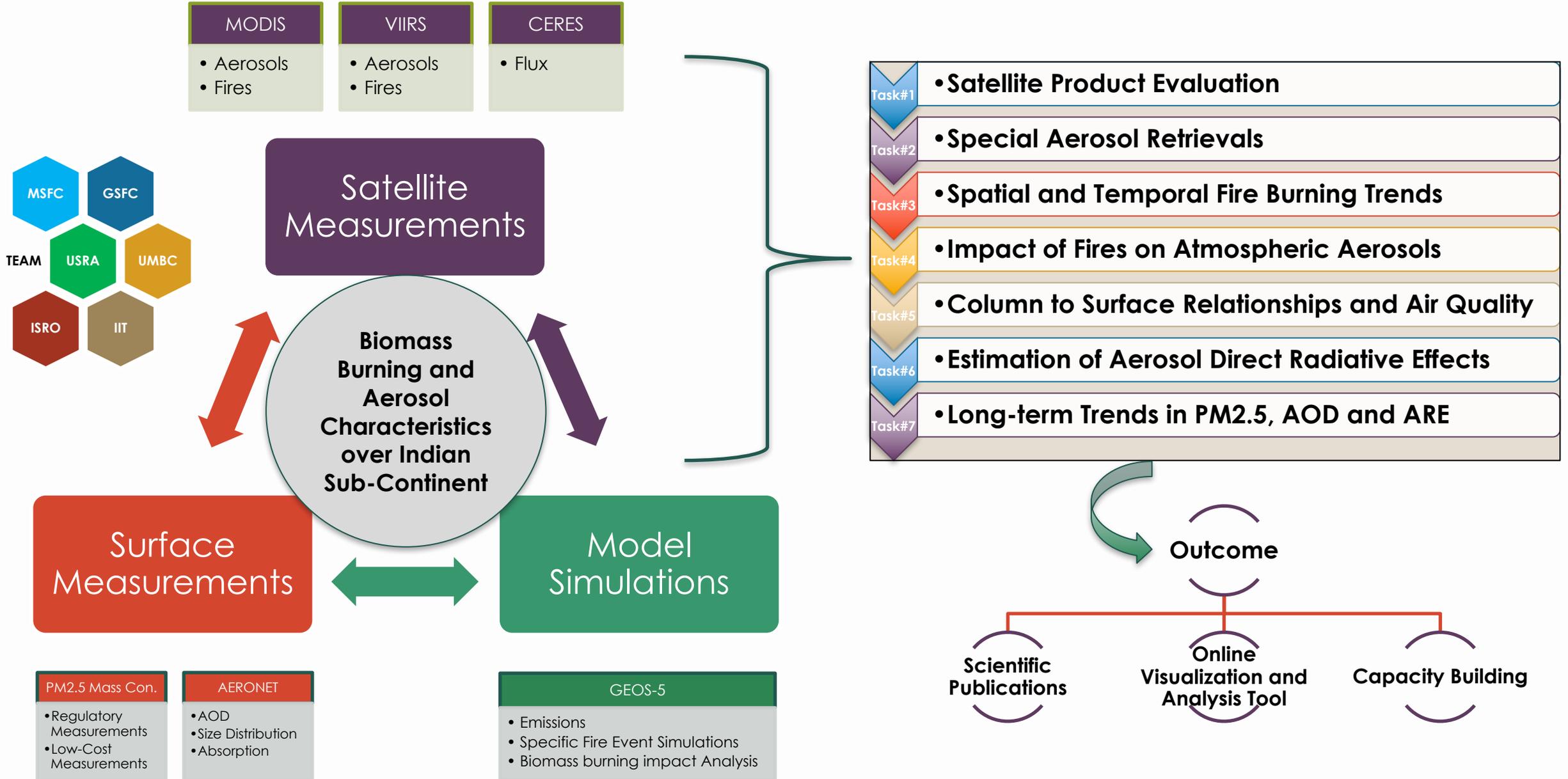
In order to understand the changing nature of aerosols and its implications for AQ and regional radiation budget, continuous monitoring of aerosols is required

An aerial satellite photograph of a coastal region, likely the Gulf of Mexico. The image shows a mix of land and water. The land is a mix of brown, tan, and green, indicating different terrain types and vegetation. The water is a deep blue. A large, semi-transparent white rectangular box is overlaid on the center of the image. The text "Moving Forward" is written in a bold, black, sans-serif font within this box. Below the text is a solid black horizontal line.

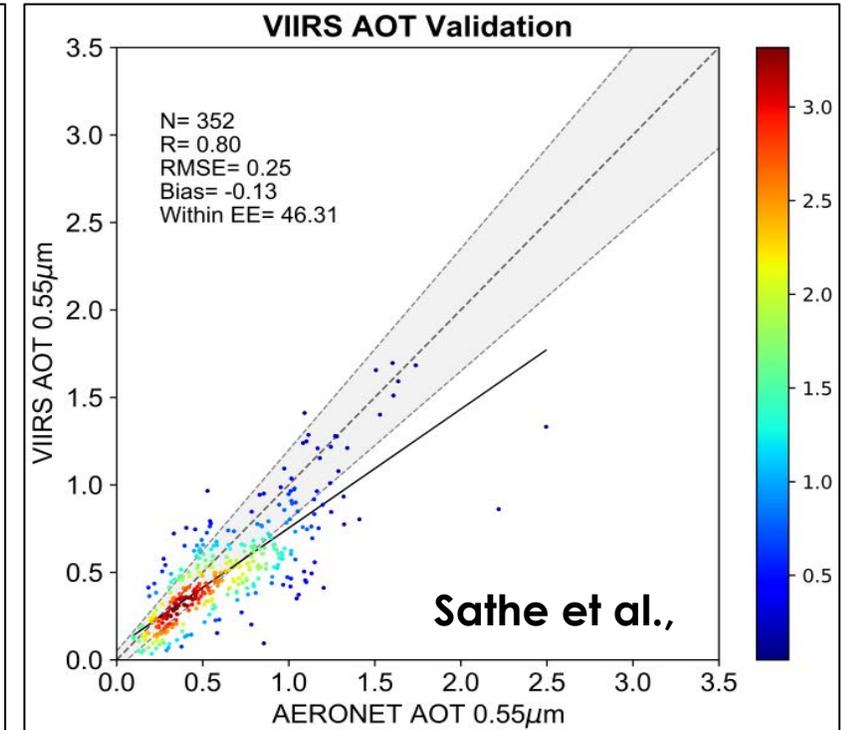
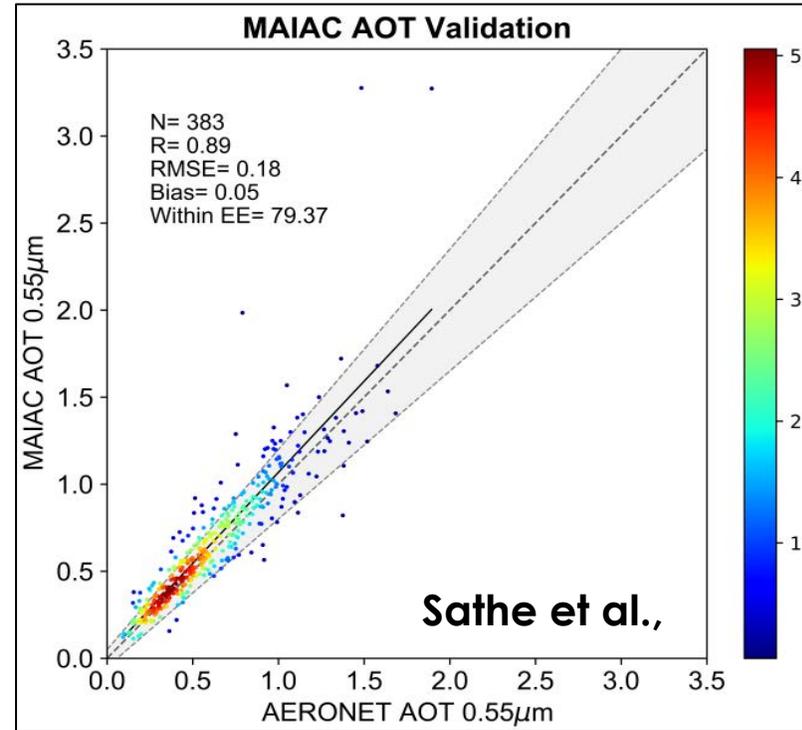
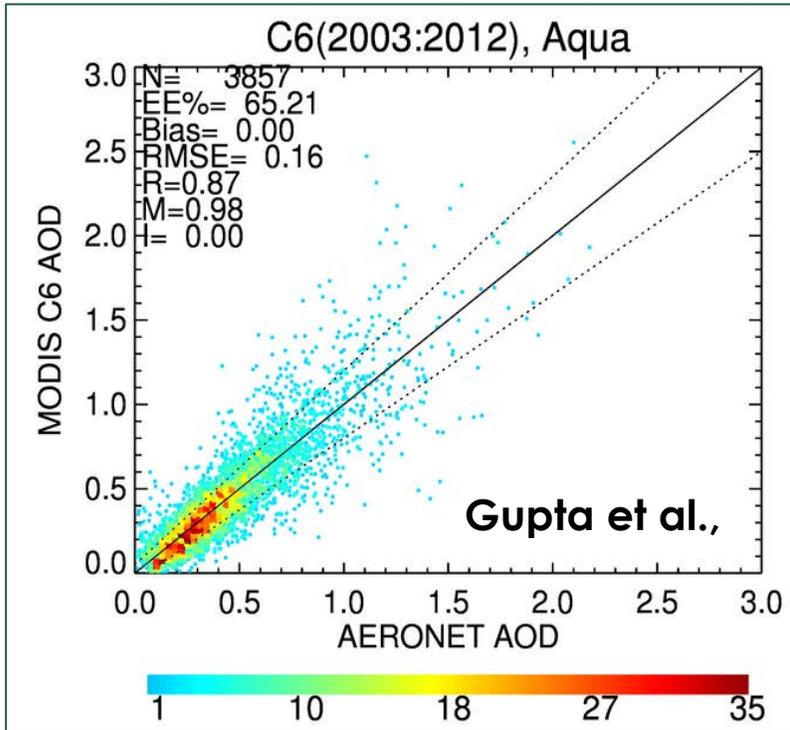
# Moving Forward

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# Characterizing Nearly Two Decades of Biomass Burning Over The Indian Sub-Continent Using Satellite, Surface and Model Simulations



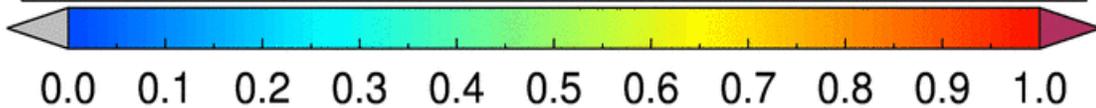
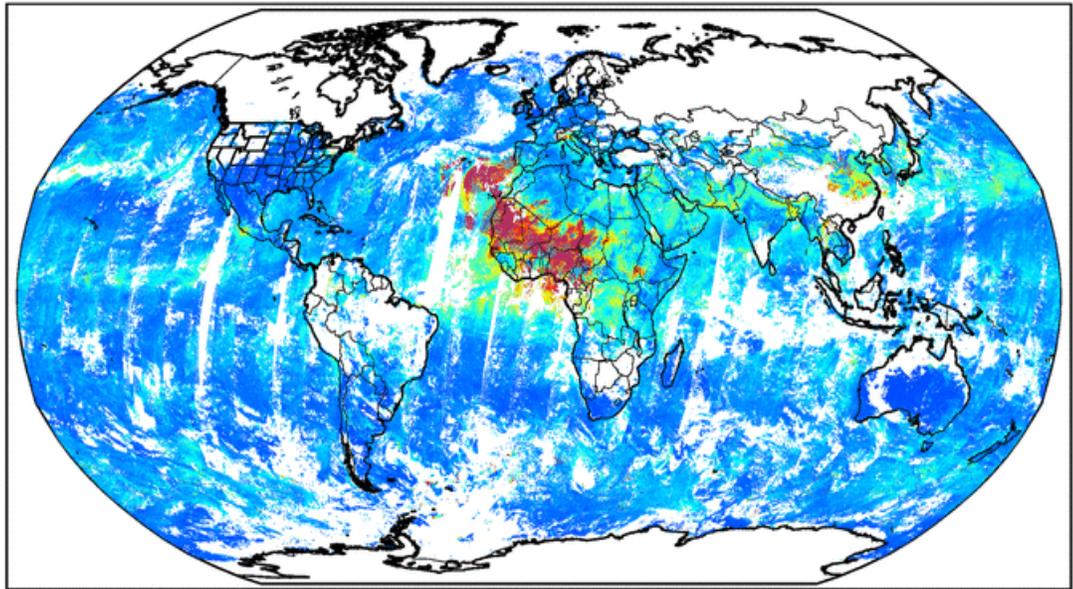
# Aerosol Data & Validation - India



We plan to validate MODIS (DT, DB, MAIAC) and VIIRS (750 m) AODs before using for AQ & Radiative forcing

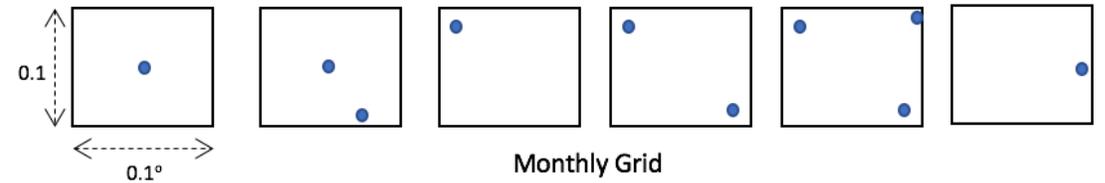
# High Resolution Gridded Product

MODIS-TERRA AOD at 550 nm: 200002

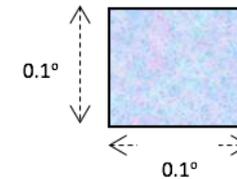


MODIS High Resolution Level 3 Gridded Data Sets

Some Potential Cases in Daily Grids



Monthly Grid



- Arithmetic Mean AOD
- Median AOD
- Standard Deviation
- Minimum AOD
- Maximum AOD
- Number of Days with valid AOD

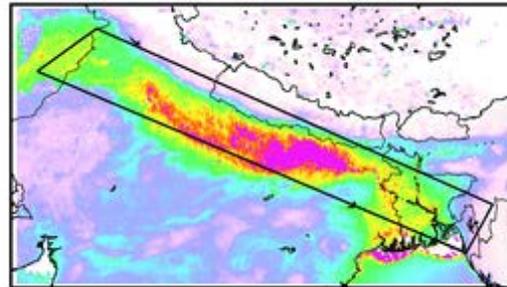
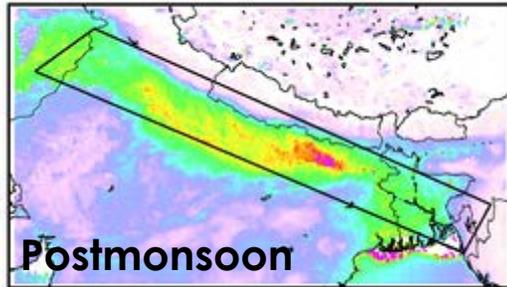
MYD04\_L3.HighRes.YYYYMM.nc  
MOD04\_L3.HighRes.YYYYMM.nc

Visualization tool for this data is under development

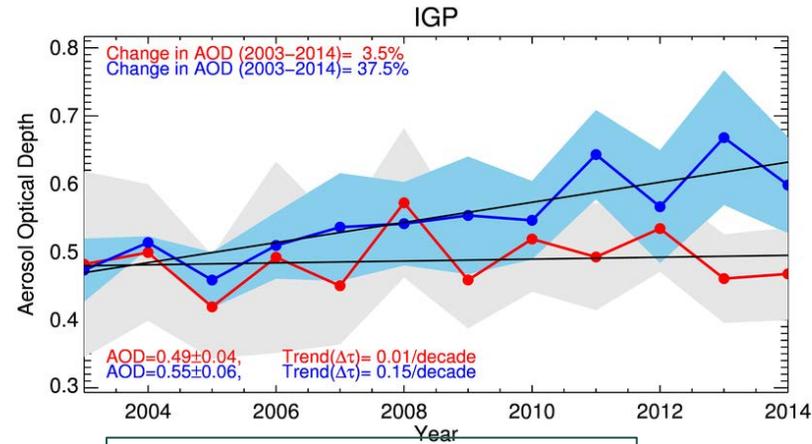
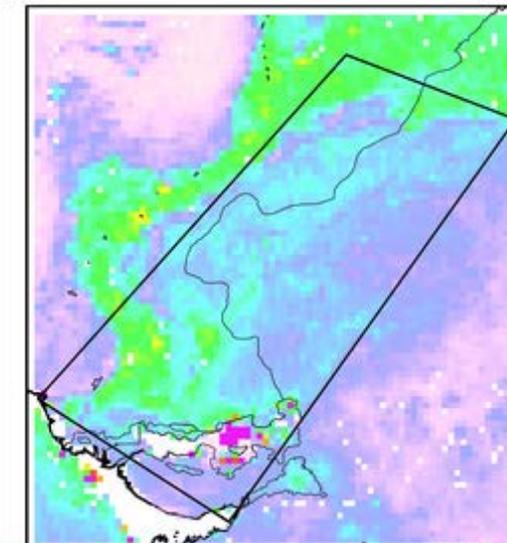
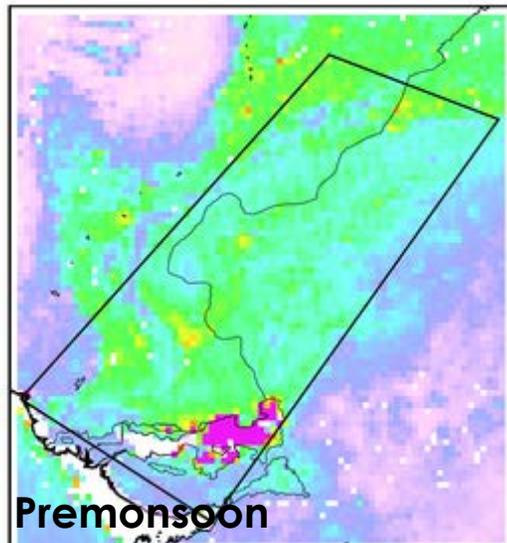
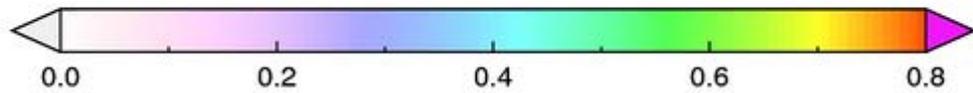
# Regional Contrast in Aerosol Trends

2003-2007

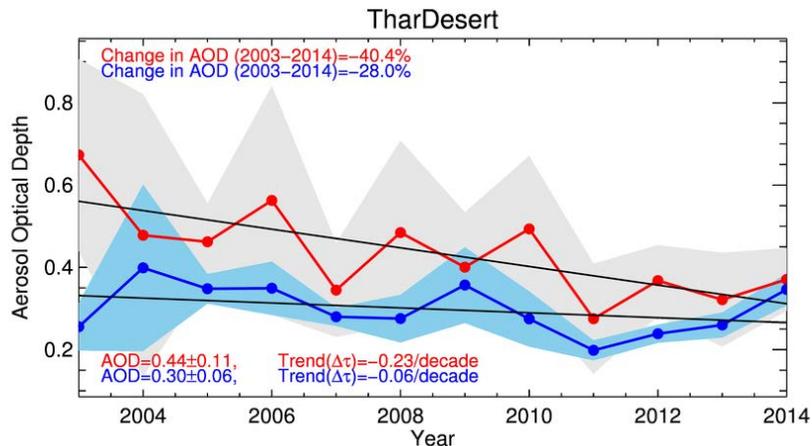
2008-2014



Aerosol Optical Depth at 550 nm

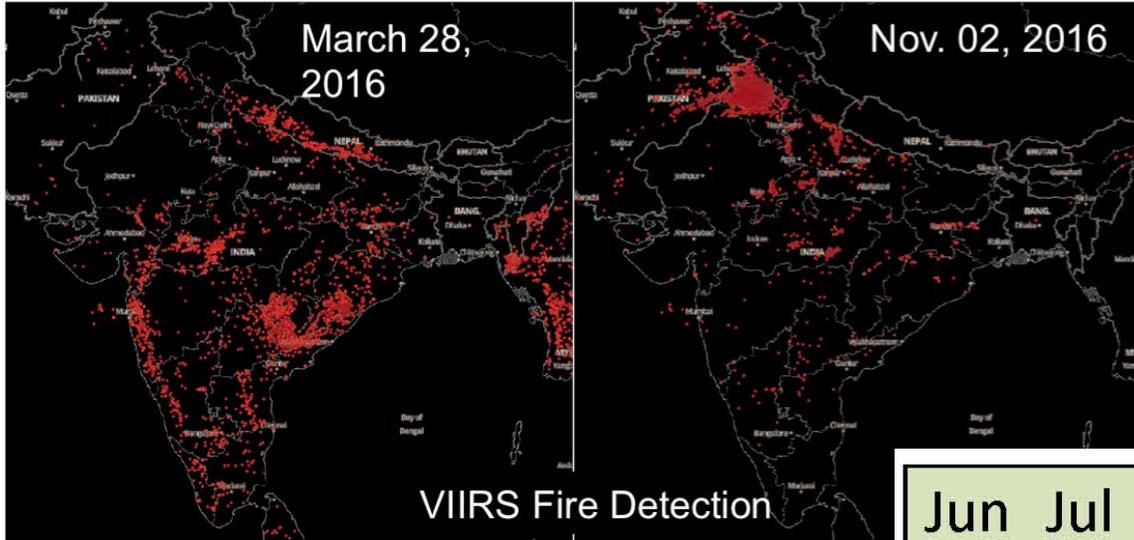


Premonsoon  
Postmonsoon



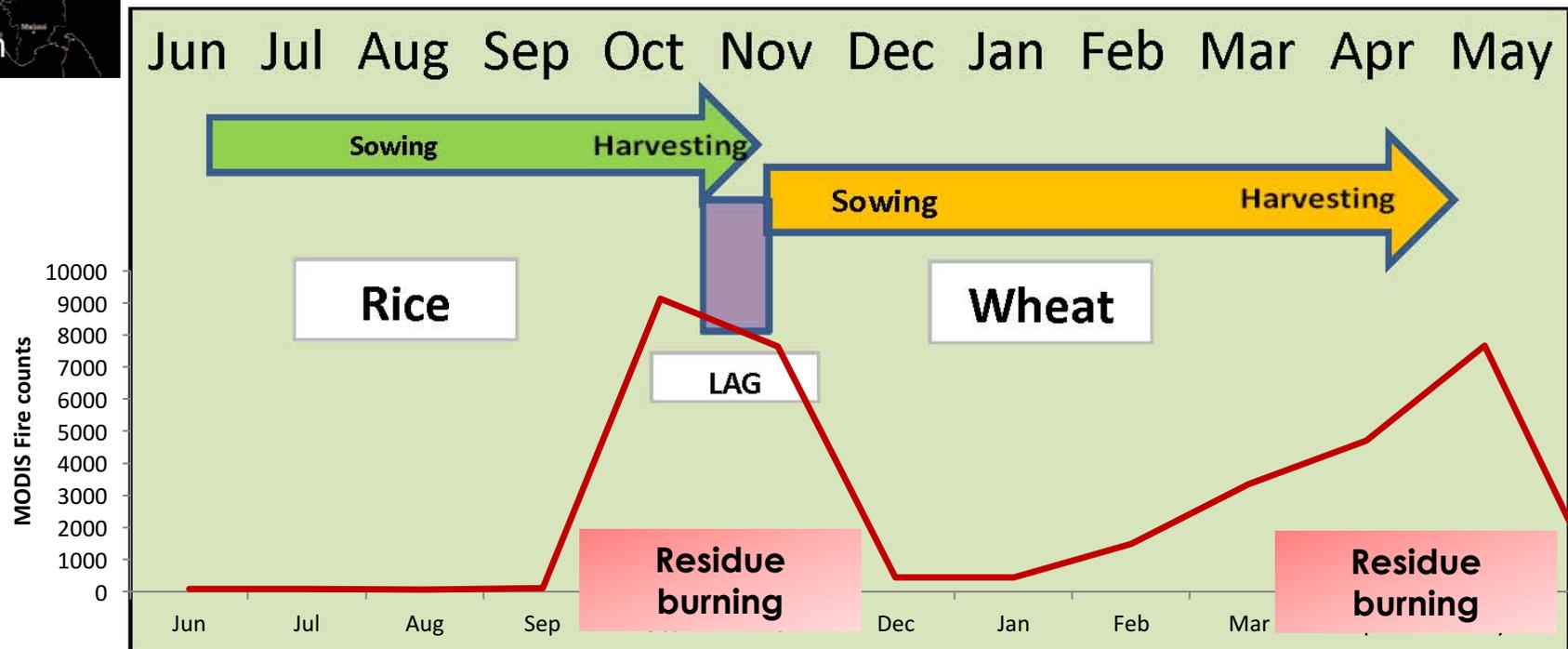
IGP is highly influenced by mineral dust during premonsoon and sea salt during monsoon, while during postmonsoon fine mode aerosols dominate

# Seasonal Pattern of Fires

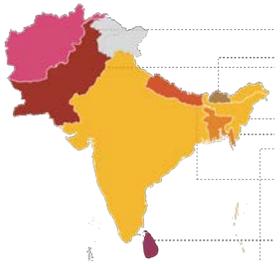
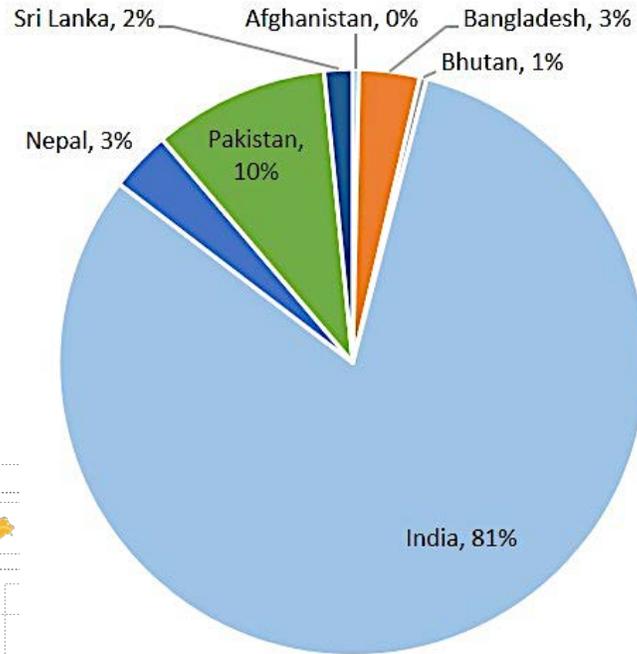


VIIRS fires detected on March 28, 2016 (left) and Nov. 2, 2016 (right). In March we see much burning in central and southern India (agricultural and open fires) and some fires in the IGP and Nepal (forest fires). On Nov 2nd, 2016 the fires have migrated to Northern India, and Pakistan (Image Generated using Worldview).

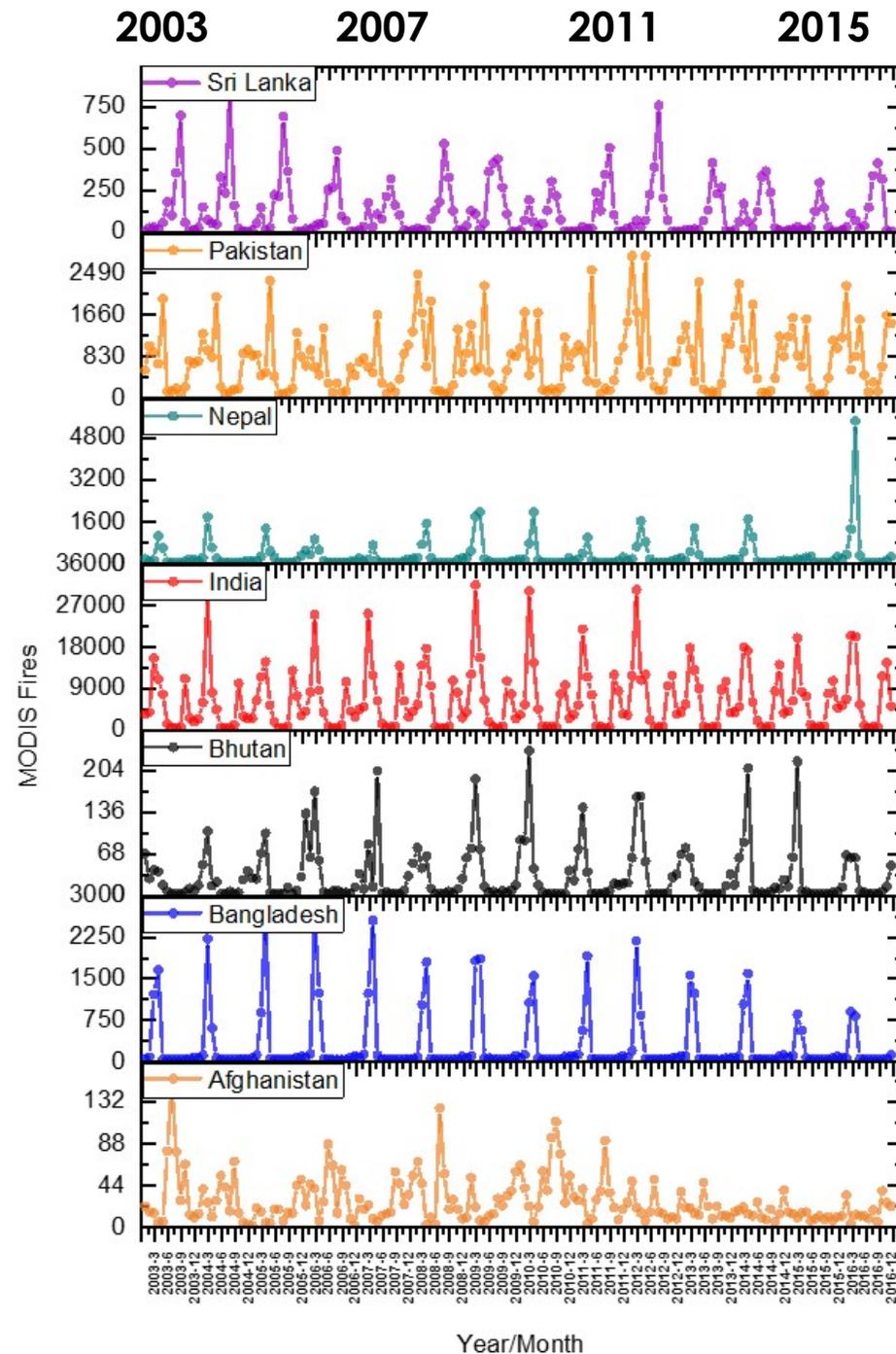
Agricultural fires show bimodal trend corresponding to Rice-Wheat residue burning



# Vegetation Fires in South Asia



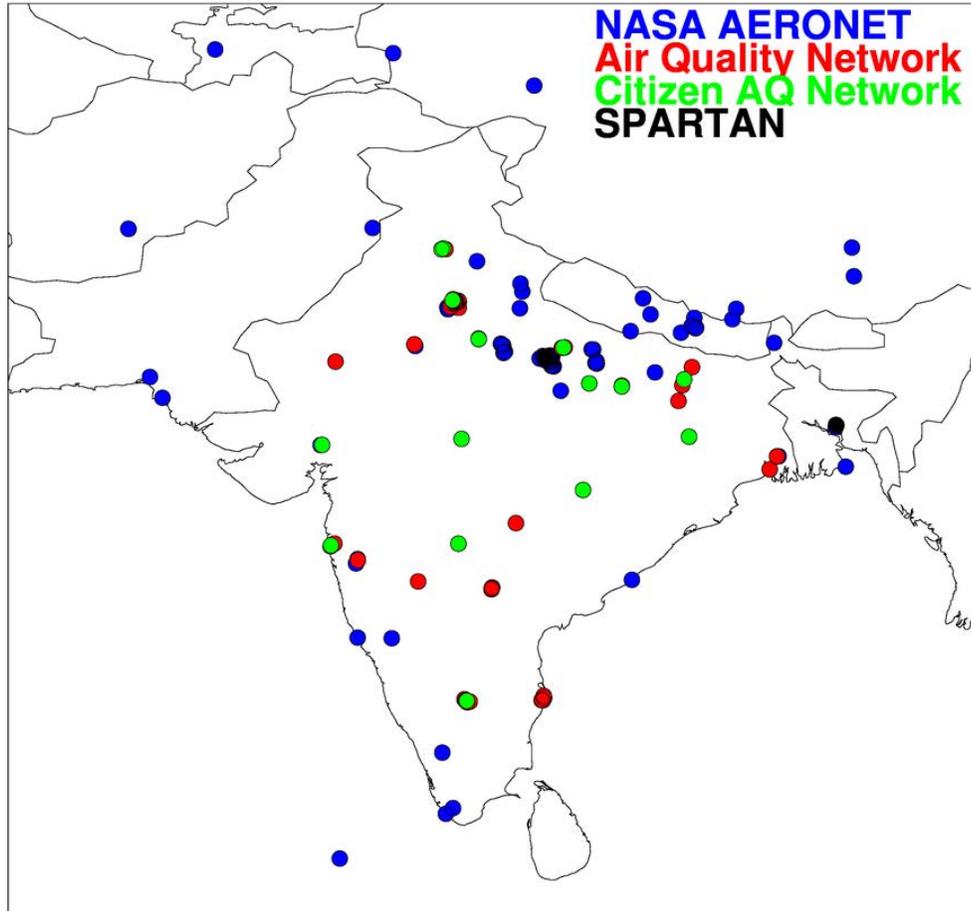
India accounts for 81% of the total vegetation fires in South Asia.



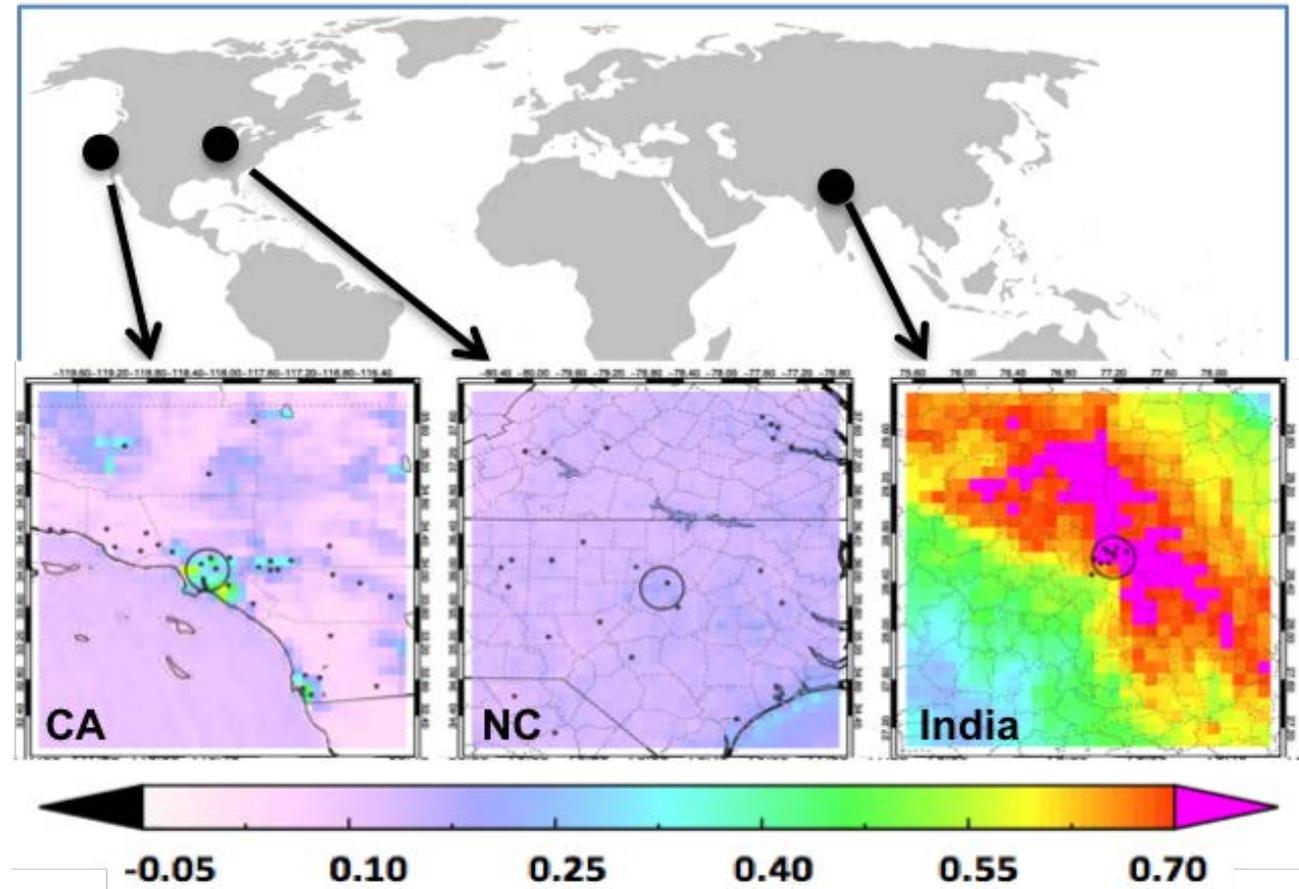
Trends in vegetation fires over different South Asian countries suggests a decreasing trend

(Vadrevu et al., 2018 ERL, submitted).

# Surface vs Column

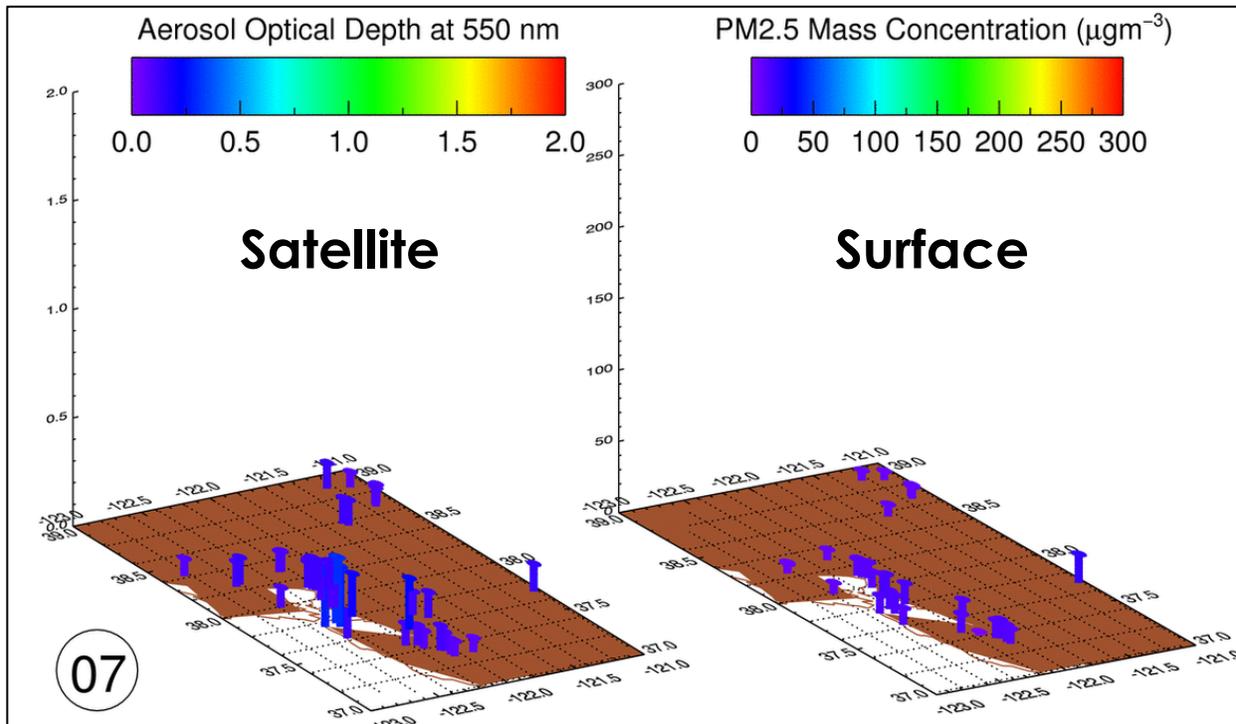


# Leveraging NASA Citizen Science Project – Deploying Low-Cost AQ sensors in India



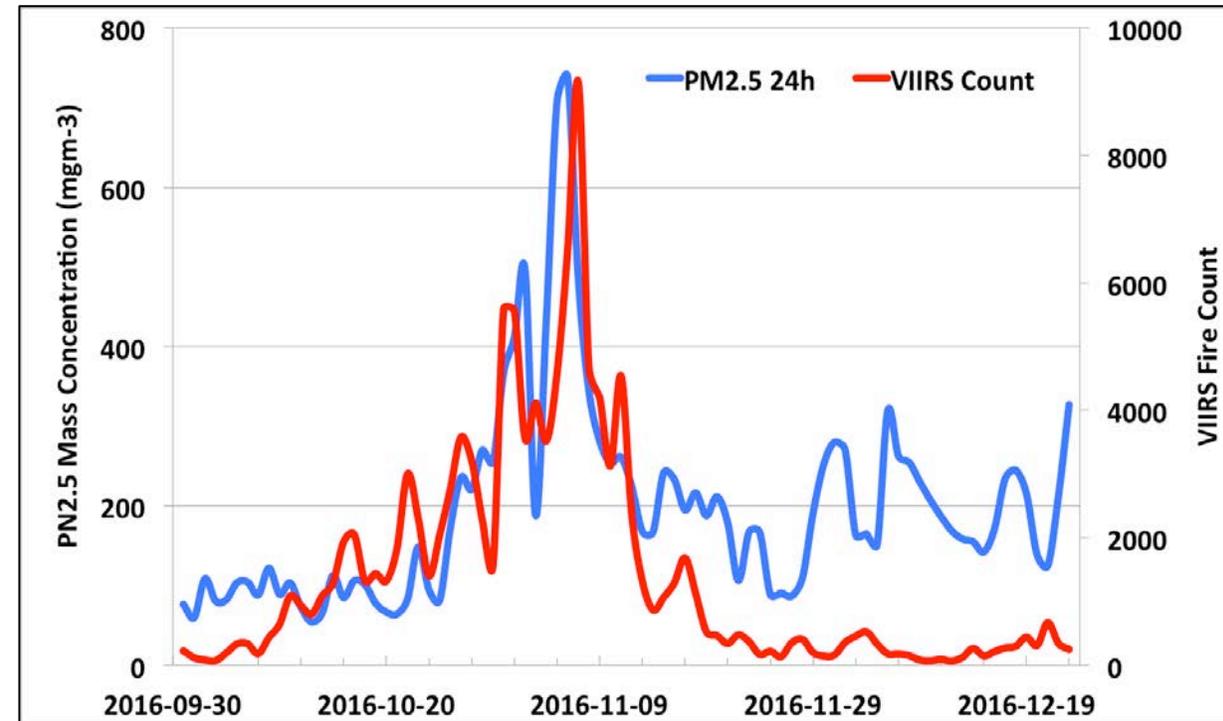
# Impact of Biomass Burning on Air Quality

## Satellite and Surface Measurements Respond to Change in Air Quality During Fires in CA

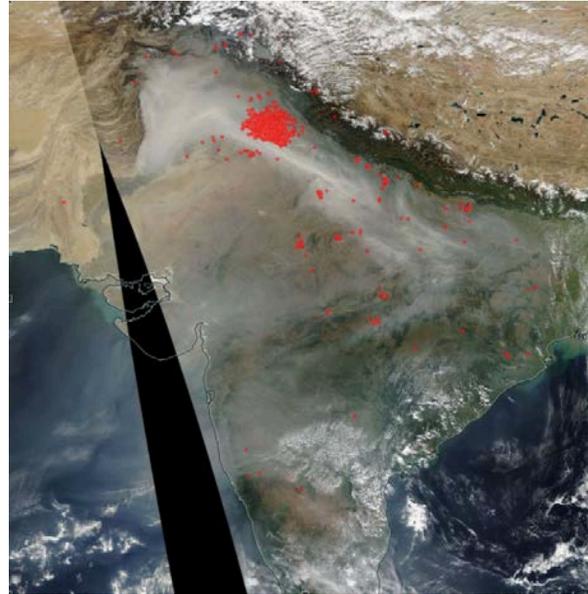
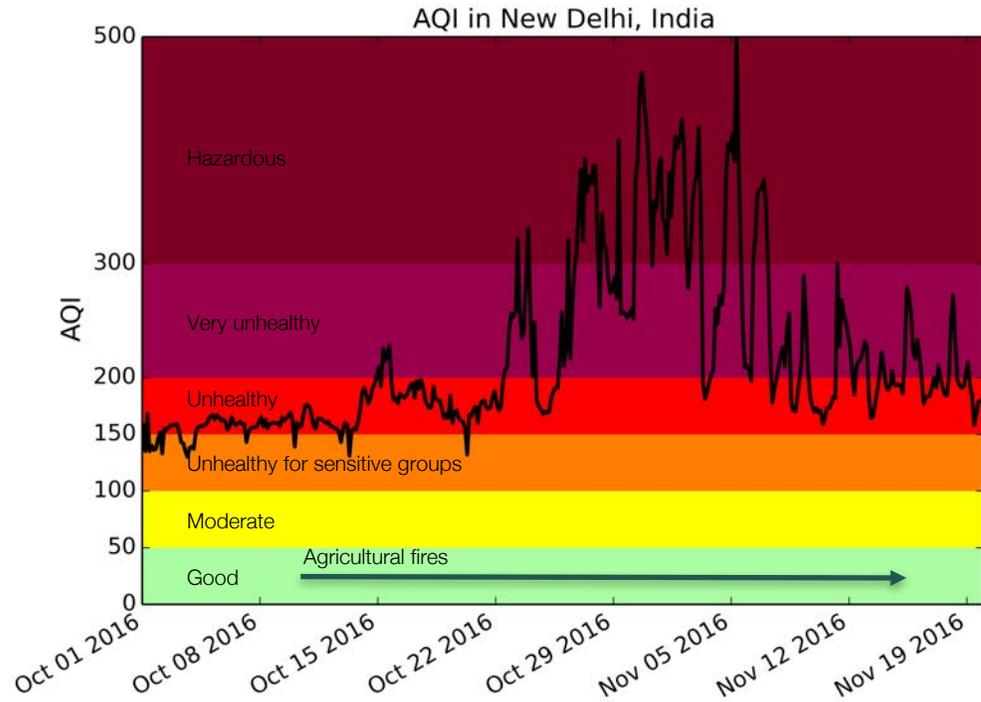


Gupta et al., 2018

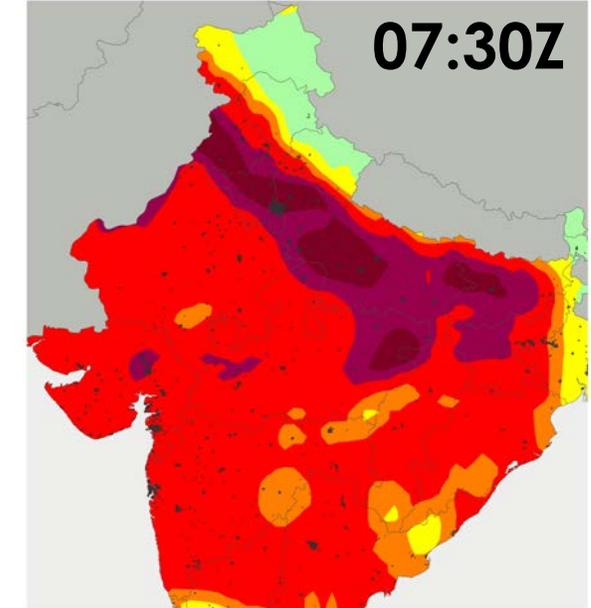
## VIIRS Fire Counts & PM2.5 – Delhi, India



# Model Simulation - November 06, 2016



GEOS/FP combined (PM, SO<sub>2</sub> and CO) air quality index (AQI)



From; Darmenov et al.,

- **GEOS experiments**

- **Experiment 1: Full set of emissions**
- **Experiment 2: No biomass burning emissions**

## Goals:

- Estimate contributions due to fires, dust and other sources
- Identify biases in the forward model
- Correct the biases in PM<sub>2.5</sub> and find the contribution of the fires to the AQIs

# Challenges & Approaches

- Various visual satellite images and correlation analysis suggests the impact of fires on aerosol loading, there is little direct proof.
- during the post monsoon season, aerosols originate not only from crop burning, but also from domestic heating (due to cold temperature) and industrial & vehicular pollution.
- during the spring/summer fire season, dust is added to the mix, which create another layer of complexity and requires a different approach.
  - Long-term background aerosol climatology. This background should include all “normal” particle producing activity, with fires adding an “abnormal” positive perturbation to these values.
  - Explore multiple spectral/spatial tests to identify and retrieve smoke aerosol optical depth
  - CALIPSO climatology of aerosol typing will also be explored
  - Model simulations with improved emission data sets

# Summary

- The ISC is suffering from overwhelming burdens of particulate air pollution and creating significant radiative perturbations to the regional and perhaps global energy balance.
  - How much of this burden is due to smoke from fires?
  - How has the contribution from biomass burning changed over the years?
  - How can we inform policy decisions that will begin to mitigate this burden and perturbation?
- With nearly two decades of satellite aerosol and fire detection products, advanced global modeling system, combined with a network of ground measurements in the region, we aim to begin to answer some of these questions.